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Meteoritic Time-of-Fall Patterns

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ABSTRACT

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The yearly and monthly time-of-fall patterns for all meteorite falls and for certain types of meteorites were examined for departures from randomness. The histogram of falls per decade contains at least three peaks and a sharp decrease after 1940 which is believed to reflect a decrease in the rate of influx of meteorites. The yearly fall pattern of the calcium-rich achondrites parallels the peaks in the falls per decade histogram very closely. The only monthly fall pattern which appears to depart greatly from randomness is that for the veined-olivine-hypersthene chondrites.

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INTRODUCTION

The time-of-fall patterns for meteorites should reflect the types of orbits these bodies follow and these in turn should be indicative of their origins and histories. Several authors concerned with meteorites have attempted to interpret their time-of-fall patterns and other statistics connected with their recovery (Farrington, 1915; Fisher, 1933; Leonard and Slanin, 1941a, 1941b, 1941c; Russell, 1947). The present study was undertaken because of the addition of important data in the last fifteen years and because of the progress made in a more general survey of meteorite statistics conducted by the authors using punch-card sorting techniques. The time-of-fall patterns with which we shall be concerned in this paper are those showing the number of falls as a function of year (or decade), as a function of month (or 10-day interval), and to a lesser extent, as a function of the hour of day.

The goal of almost all studies of meteorite fall statistics is a better characterization of the pre-atmospheric flux encountered by the earth. In order to achieve this, the physical and sociological factors which operate to change and distort the pre-atmospheric type, mass, and directional composition of the flux must be eliminated from the data for the flux arriving at the surface of the earth. These factors, which affect the probability of recovering fallen meteorites, may be divided into two catagories:

(1) the intrinsic factors due to the chemical, physical, and orbital characteristics of each meteorite which determine:

(a) its resistance to ablative losses during passage through the atmosphere;

(b) its behavior upon striking the surface of the earth;

(c) its resistance to weathering; and

(d) the degree to which its appearance is dissimilar to that of terrestrial rocks;

(2) the extrinsic factors, which are present in the region of fall:

(a) the time of day;

(b) the season of year;

(c) the soil, climatic, and topographical features;

(d) the population density;

(e) the cultural level of the population; and

(f) the position of the antapex of the earth's motion with respect to the horizon (since more meteorites are recovered falling from that direction than from the direction of the apex of the earth's motion - Fisher, 1933).

If we assume, as a first approximation, that the type, mass, and directional composition of the pre-atmospheric meteoritic flux has remained constant with year, month, and hour for the last 150 years, then the observed time-of-fall patterns should show the following affects:

(1) changes in factors 2d and 2e should produce a continuously increasing curve for the number of falls each year;

(2) factor 2b in either hemisphere should produce a maximum during the summer months and a minimum during the winter months in the curve showing the number of falls as a function of month; and

(3) factor 2a should produce a maximum during the daytime hours and a minimum during the nighttime hours in the curve showing the number of falls as a function of the hour of day. Since we have postulated a flux with a constant composition, these effects should operate to an equal extent upon the time-of-fall patterns for each type of meteorite.

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Before considering the statistical data, we will consider the possible sources of meteorites and other pertinent facts in order to establish criteria for examining these data.

POSSIBLE SOURCES OF METEORITES

A model in which the moon acts as a source of tektites has been considered by Varsavsky (1958) and O'Keefe (1959) with primary meteorite impacts ejecting secondary fragments from its surface. These fragments should follow trajectories direct to earth (ejection velocities greater than 2.3 km./sec.) and also enter earth orbits (ejection velocities in the range 2.3 to 2.7 km./sec.) and solar orbits (ejection velocities greater than 2.7 km./sec.). The asteroid belt is most often considered as a source of meteorites with collisions between asteroids presumably yielding fragments in orbits some of which have perihelia inside the earth's orbit. Other sources of meteorites which have been proposed include: (1) comets from which meteorites would be ejected along with meteors yielding streams containing both sizes of bodies; (2) the breakup of a single large planet in the remote past; (3) primordial remnants of planetary accretion; and (4) interstellar space, from which hyperbolic meteorite orbits would be observed.

The time-of-fall patterns for bodies traversing trajectories direct to the earth from the moon would be determined by the time-of-fall patterns of the primary bodies striking the surface of the moon. Fragments travelling in orbits about the earth are members of a three-body system and we would expect their time-of-fall patterns on the earth to be influenced to some degree by the position of the moon. The time-of-fall patterns for bodies travelling in solar orbits should be random in year and month if these bodies are not members of streams. However, their hourly fall patterns should reflect the distribution of their eccentricities and semi-major axes. If these bodies are members of streams and are bunched along the orbit of the stream, their yearly, monthly and hourly patterns should be non-random. Bodies which are members of streams but are not bunched should display non-random monthly and hourly fall patterns and random yearly fall patterns unless the node of the orbit of a stream is being swept across the orbit of the earth, in which case several centuries of fall should take place preceded and followed by no falls from this stream. The time-of-fall patterns for interstellar meteorites traversing hyperbolic trajectories should be random unless an uneven distribution of meteorites exists in interstellar space, in which case a non-random yearly distribution might result.

Other facts pertaining to the origins of the meteorites which should be considered are:

(1) The cosmic-ray exposure ages, which date the time since the reduction of meteorites to meter-sized fragments, do not confirm any single theory of meteoritic origin (Anders, 1962). The ages tend to cluster in three groups with the chondrites centered at 22 million years, one group of irons at 200 to 300 million years, and a second group of irons (primarily medium octahedrites) at 500 to 600 million years. In Table I are shown the exposure ages for meteorite falls which are included in the data to be presented.

(2) The lifetimes for bodies crossing the orbits of the inner planets, as shown in Table II, are of the order of 10^8 years (Opik, 1950a, 1951, 1958, 1961). Therefore the meteorites cannot have been in their present orbits since the formation of the solar system and must have been injected into

these orbits from somewhere else.

(3) Accurately measured meteorite fall trajectories, which can be used to calculate the solar system orbit, are very difficult to obtain. Some of the orbits which have been calculated are shown in Table III but the quality of these data varies widely. The greatest reliance should be placed on the Pribram orbit which is the only one based on photographic evidence. It is perhaps significant that most of the other orbits listed are similar to the Pribram orbit. It should be noted that Wylie's Pultusk orbit is disputed by Opik (1950b) and LaPaz (1958) in a continuing debate over the presence of hyperbolic meteors and meteorites (Whipple and Hughes, 1955).

(4) Meteorite time-of-fall patterns do not display any noticeable relationship to those for meteor streams (Farrington, 1915).

(5) The frequency vs. mass distribution for meteorites is similar to that for the asteroids (Hawkins, 1959a, 1959b; Brown, 1960). It should be stated, however, that the mass data for the meteorites are taken from the Catalogue of Meteorites (Prior and Hey, 1953) and represent the amount actually recovered. It is reasonable to question whether this mass distribution is the same as the pre-atmospheric distribution.

Although hyperbolic and cometary components may exist, it still seems most logical to look to the asteroid belt for the immediate origins of most meteorites. Mean values for the relative collision velocities between asteroids were calculated by Piotrowski (1952), who found 5 km/sec., and by Opik (1955), who found 6 km./sec. Piotrowski further found that catastrophic collisions between typical asteroids take place with life-times of the order of 10^9 years.

FALLS PER DECADE

Figure 1 shows the number of falls for each decade from 1680 to 1960. The cross-hatched areas for the twentieth century will be explained below. The distribution is obviously not uniform. There is an almost linear rise from 1780 to 1940, peaks are located at 1750-80, 1810-30, 1860-80, and 1930-40, and a sharp decrease occurs after 1940. The linear rise is usually attributed to the increasing chances of recovering meteorites due to the increases in the population density and scientific cultural level (Heide, 1957). The peaks are ordinarily attributed to statistical fluctuations and the decrease after 1940 is thought to result from the incomplete statistics on the recovery of meteorite falls since 1940. Figure 2 shows the falls per decade data normalized to the world population. There is still an increasing recovery rate and the peaks are more apparent. While Farrington (1915) noted the increase during the decade 1860-70, he thought the distribution reflected a comparatively uniform supply of meteorites with no evidence of cycles or periodicity. Several authors have gone beyond these usual explanations and searched for non-uniformity in the distribution. Russell (1947) assumed a linear rise in the recovery efficiency and, by examining the residuals for each year, he found the fluctuations for the years 1868 and 1933 were statistically unlikely to be random. Paneth (1949, 1956) made comparisons between the increasing meteorite recovery rate and the much faster increasing rate of discovery of asteroids and of ball lightening and concluded that meteorite falls have become increasingly rare since 1800. In order to examine the reality of the fluctuations during the twentieth century, we will study the effect of war and the effect of the delay in reporting meteorite falls.

Table IV shows the data which pertain to the effect of war. The decade 1940-1949 is divided in half to show the effect of World War II. India and Pakistan are considered separately from the rest of Asia. We may note that in Europe, the periods with the lowest recovery fractions coincided with the two World Wars (1914-18, 1939-1945), and in Asia, the lowest fraction coincided with World War II. In India and Pakistan, there appears to have been a sizeable reduction in the recovery rate during the five years which encompass partition (1946-47), although the recovery fraction for 1940-49 appears to be normal. Africa and Central and South America were probably least affected by World War II. Their recovery fractions for 1940-49 show opposite trends, but this is probably due to poor statistics. It seems clear that a decrease in the meteorite recovery efficiency does take place during major conflicts and disorders and that this decrease may be as hign as thirty percent for particular regions during certain decades. The increase in the number of falls per decade assigned to a region affected by a major conflict was calculated by assuming that the recovery fraction should be equal to the average for 1900-49 for that region. The results are shown in column 3 of Table VI.

Table V was used to study the effect of the delay in reporting meteorite falls. This table shows the fraction of the falls eventually reported which had been reported within certain elapsed periods of time. These were calculated for each meteorite by noting the date of the earliest reference in the <u>Catalogue of Meteorites</u> and subtracting the actual date of fall or find. Two opposing factors affect the statistics. First, the earliest reference date in this catalogue may not in fact be the earliest reference which brought the meteorite to the attention of the scientific community. Secondly, the earliest reference may have been in a rather obscure journal and the major portion of the scientific community may not have noted the meteorite until later. Of these two factors, the first will be assumed to be the more important, particularly at the present time when communications concerning new meteorites are very rapid due to The Meteoritical Bulletin. Therefore, the gradients of the growth curves from these data will be assumed to be lower limits and the actual reporting of meteorite falls assumed to take place with shorter delays. It is interesting to note from these data that the gradient has not changed very much since 1800-1850 and the apparent increase for 1900-1950 is probably due to the fact that the totals used to calculate the fractions for this period are not yet complete. In addition, the gradient for falls is initially much steeper than that for finds but essentially the same fractions of both have been reported by about 20 years.

The data given by Farrington (1915) and Leonard and Slanin (1941c) on the numbers of falls recovered per decade up to 1910 and 1940 respectively provide an independent check on the value for the gradient. Table VII shows the data for the numbers of falls and Table VIII shows the fractions calculated from these data. The gradients in this table tend to confirm the rather steep gradient in Table V.

The increases over presently tabulated meteorite falls to be expected for the twentieth century decades were calculated using the averages for falls during 1800-1950 in Table V. The results are shown in column 4 of Table VI. Finally, column 5 of this table indicates the total number of falls to be expected if no wars had taken place and if all falls had been reported by now. The increases over the presently tabulated totals are shown as cross-hatched areas in Figure 1. Even when these corrections are applied, the very sharp decrease after 1940 is still present, and since the recovery efficiency, if anything should have increased since this date, the decrease probably reflects a decrease in the intensity of the meteorite flux encountered by the earth.

MONTH VS. YEAR OF FALL

We now wish to examine the meteoritic month vs. year fall patterns for various types of meteorites looking for departures from randomness in the yearly and monthly distributions, contributions to the peaks found in the falls per decade histogram, and any departures from randomness in various areas of the graphs. The division of the data on the basis of the type of meteorite was made in order to uncover any variations in the time-of-fall patterns which might be indicative of different origins or at least different immediate parent bodies. Whether or not we observe any differences in the month vs. year time-of-fall patterns will, of course depend on whether the immediate parent bodies were located in the same region (e.g., the asteroid belt), the number of immediate parent bodies contributing to any particular type of meteorite, and the rate of dispersal of any unique distribution of meteorites produced as a result of the fracture of the immediate parent body. The division of the data was made using Mason's classification of meteorites (1962) whenever it conflicted with that in the <u>Catalogue of Meteorites</u>.

The degree of randomness in these distributions was evaluated by applying the chi-squared test. Since the numbers of meteorites in many categories is small, synthetic random distributions were generated from a random-digit table (The Rand Corporation, 1955) for purposes of comparison and to gain some insight into the chances for the occurence of "non-random appearing" assemblages. These synthetic distributions contained varying numbers of points in order to facilitate comparison with distributions containing similar numbers of meteorites. The results of the chi-squared test applied to the ten synthetic month vs. year distributions shown in Figures 3, 4, and 5 plus sixteen other synthetic monthly distributions (not here shown) are given in Table IX. P is the probability that a particular distribution is random (i.e., the probability that a random sample will give a no better fit to a uniform distribution) and this probability should be less than 0.02 before a departure from randomness is assumed (Garrett, 1937). We should note that the breakdown of data according to month and decade in order to apply the chi-squared test may conceal non-randomness present on a finer scale. In addition, we should expect special types of non-randomness to be present in the monthly distributions due to the variation of recovery efficiency with decade and in the decade distributions due to the growth of population. Figures 3 and 4 indicate that random distributions containing only 20 or 40 points do display "non-random appearing" groupings of points in the graphs and histograms and therefore, caution must be used when evaluating the randomness of distributions containing small numbers of points.

The actual meteorite distributions are shown in Figures 6 through 9 and the chi-squared test results in Table X. We may summarize the observations concerning these distributions as follows:

Enstatite chondrites: The monthly distribution appears to be random. There were no falls of this type recorded prior to the 1860's but this may be due to the fact that there are only 9 of these meteorites. There may be a contribution to the 1860-80 peak in the falls per decade histogram but none to the 1930-40 peak.

Olivine-pigeonite chondrites: The monthly distribution appears to be random. There were no falls of this type recorded prior to 1857 or after 1930 but this may be due to their small number. 1855-85 and 1900-11 groups appear. The former group contributes to the 1860-80 peak in the falls per decade histogram. A July, 1860-80 group is prominent.

Carbonaceous chondrites: Both the monthly and yearly distributions appear to be random. There does not appear to be any contribution to any of the peaks in the falls per decade histogram with the possible exception of 1930-40.

Olivine-bronzite chondrites: The monthly distribution appears to be random. In the yearly distribution, groups appear around 1870 and 1930. In addition, there appear to be departures from randomness during January, 1867-9 and May, 1855-93.

Olivine-hypersthene chondrites: The chi-squared test indicates that the monthly distribution for this large body of chondrites borders on non-randomness. The yearly distribution appears to be non-randum with high rates of fall during the decade 1920-30 (21 falls as opposed to an average of only 11 per decade). There is a suggestion of a 16-year periodicity during February. Groups exist during May-June, 1827-77, June 21-30, July 1910-30, December, 1846-90, and December 1918-40.

Veined-olivine-hypersthene chondrites: There is very small probability that the monthly fall pattern is random. No falls occurred in March. The yearly pattern appears to be random with no contribution to the 1920-30 olivine-hypersthene group. However, there is contribution to the May-June, 1827-77 group.

Low-iron and high-iron chondrites: These classes of chondrites are dominated by the olivine-hypersthene and olivine-bronzite chondrites respectively and thus reflect the characteristics of these distributions.

Calcium-poor achondrites: The number of falls in the monthly distribution is too low to draw any conclusions concerning randomness. A gap exists in the decade distribution during 1889-1919 but comparison with the synthetic random point distributions containing 20 points (Fig. 3) indicates that this is not unusual.

Calcium-rich achondrites: The monthly fall pattern appears to be random but groupings in the yearly distribution coincide with the peaks in the falls per decade histogram. There is a suggestion that the 1900-10 shoulder on this histogram may be due to another peak as evidenced by the 1900-10 grouping for this class of achondrites. It is not shown by the graph, but a concentration of nighttime falls exists around February-April, 1930-40.

Irons: Although the monthly distribution appears to be random, there is a low probability that the yearly fall pattern is random. The rate of recovery of iron falls increased after 1898 (1848-1897 = 6 falls when the total was 218, 1898-1947 = 26 falls when the total was 299). A concentration of falls exists during July-August, 1933-35.

SUMMARY AND CONCLUSIONS

The falls per decade histogram demonstrates that the meteorite flux has not remained constant during the last 200 years, but has gone through at least three and possibly four maxima. The precipitous decline in the rate of recovery of falls since 1940 cannot be explained entirely on the basis of incomplete reporting of recent falls nor by the advent of World War II and must therefore reflect a decrease in the rate of influx of meteorites. Among the various monthly fall patterns, only that for the veined-olivine-hypersthene chondrites appears to be definitely non-random; however, there is no apparent correlation between the monthly groupings and the year of fall. Among the yearly fall patterns for the various types may be found definite contributions and lack of contribution to the peaks found in the histogram of falls per decade.

Most notable among the contributions are the calcium-rich achondrites whose yearly fall pattern parallels the falls per decade pattern quite closely. Due to observational factors, we should expect higher recovery rates during the summer months to distort the monthly distributions and the increasing recovery efficency due to population growth to distort the yearly distributions but these trends are not observed with any regularity for individual meteorite groups.

This study of meteoritic time-of-fall patterns resulted in no definite conclusions as to the types of orbits followed by meteorites and therefore their origins are no less obscure. However, the following features which did emerge from the study of these patterns must be explained by any theory of meteoritic origin:

(1) long term (about 2 centuries) and short term (about 60-year) variations in the flux;

(2) differing time-of-fall patterns for different types of meteorites; and

(3) the presence of non-random monthly distributions suggesting the presence of meteorite streams.

The method of dividing the data on the basis of the type of meteorite is a first approximation and perhaps a division on the basis of some other system of classification (e.g., a purely chemical one) might prove more fruitful.

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TABLE I. Cosmic-Ray Exposure Age for

Meteorite Falls (Anders, 1962)

Meteorite	Date of Fall	Type	Cosmic-Ray Age (10^6 years)		
			H^3-He^3	Ar^{39}-Ar^{38}	Others
Stones:					
Abee	6/10/1952	enstatite chondrite	13		
Mezel	1/25/1949	veined-hypersthene chond.	4.7		
Murray	9/20/1950	carbonaceous chondrite			15
Norton County	2/18/1948	enstatite achondrite	230	500	
Irons:				Preferred Value	
Braunau	7/14/1847	hexahedrite		8	
Sikhote-Alin	2/12/1947	coarsest octahedrite		220	

TABLE II. Lifetimes for Bodies Crossing the Orbit of the Earth (adapted from Opik, 1951)

Object	a (a.u.)	e	i	Half-Life (10^6 years)	Fractional Capture Probability for the Earth
Hermes	1.3	0.47	4.7°	29	0.31
Apollo	1.5	0.57	6.4°	50	0.30
Adonis	2.0	0.78	1.5°	50	0.51
Taurids and Encke's Comet	2.2	0.84	13°	190	0.26
Geminids	1.4	0.90	23°	170	0.28
objects with the same semi-major axis as the earth:					
		0.02	1°	0.3	1.00
		0.05	3°	1.9	1.00
		0.10	6°	11	1.00
		0.20	12°	62	1.00
		0.25	53°	220	1.00

TABLE III. Orbits Calculated for Meteorite Falls

Meteorite	Date of Fall	Type	a (a.u.)	q (a.u.)	q' (a.u.)	P (years)	e	ω	Ω	i	Reference
Pultusk	1/30/1868	veined-grey bronzite chond.	1.78	0.98	2.58	2.37	0.45	159.9°	310.3°	0.8°	Wylie, 1940
Tilden	7/13/1927	white hypersthene chond.	1.72	0.95	2.49	2.25	0.45	141.9°	110.4°	1.4°	Wylie, 1948
Khmelevka	3/1/1929	crystalline chondrite	1.22	0.15	2.29	1.35	0.88			28.0°	Krinov, 1960
Paragould	2/17/1930	chondrite	2.50	0.93	4.08	3.96	0.63	144.0°	328.0°	19.0°	Wylie, 1948
Archie	8/10/1932	chondrite	1.52	0.81	2.23	1.87	0.47	110.4°	138.0°	7.6°	"
Pesyanoe	10/2/1933	enstatite achondrite	2.4	0.2	4.6	3.8	0.9			(small)	Krinov, 1960
Pervomaiskii	12/26/1933	chondrite					1.0			6.0°	"
Zhovtnevyi Khutor	10/10/1938	stone					0.25			44.6°	"
Sikhote-Alin	2/12/1947	hexahedrite iron	2.16	0.99	3.33	3.16	0.54			9.4°	"
Kunashak	6/11/1949	chondrite	1.83	1.00	2.65	2.48	0.45			11.0°	"
Vengerovo	10/11/1950	chondrite					1.0			319°	"
Nikolskoe	3/6/1954	chondrite	3.8	0.9	6.7	7.4	0.76			4.2°	"
Pribram	4/7/1959	crystalline chond.	2.42	0.79	4.05	3.76	0.67	241.6°	17.1°	10.4°	Ceplecha, *et al*, 1961

TABLE IV. Rates of Recovery of Meteorite Falls as a Function of Decade for Various Regions of the World. Deviations are standard deviations assigned by assuming random arrival.

Period of Fall	Europe	U.S. and Canada	Oceania and Asia	India and Pakistan	Africa	Central & S. Amer.	Total
Number of falls by region:							
1900-09	16 ± 4.0	10 ± 3.2	10 ± 3.2	8 ± 2.8	5 ± 2.2	3 ± 1.7	52
1910-19	11 ± 3.3	11 ± 3.3	11 ± 3.3	16 ± 4.0	6 ± 2.4	1 ± 1.0	56
1920-29	17 ± 4.1	11 ± 3.3	14 ± 3.7	9 ± 3.0	6 ± 2.4	7 ± 2.6	64
1930-39	18 ± 4.2	18 ± 4.2	22 ± 4.7	7 ± 2.6	7 ± 2.6	5 ± 2.2	77
1940-44	3 ± 1.7	3 ± 1.7	3 ± 1.7	6 ± 2.4	5 ± 2.2	0	20
1945-49	5 ± 2.2	3 ± 1.7	6 ± 2.4	0	6 ± 2.4	0	20
1940-49	8 + 2.8	6 + 2.4	9 + 3.0	6 + 2.4	11 + 3.3	0	40
1900-49	70	56	66	46	35	16	287
Fraction of total for each decade by region:							
1900-09	0.31	0.19	0.19	0.15	0.10	0.06	
1910-19	0.20	0.20	0.20	0.29	0.11	0.02	
1920-29	0.27	0.17	0.22	0.14	0.09	0.11	
1930-39	0.23	0.23	0.29	0.09	0.09	0.07	
1940-44	0.15	0.15	0.15	0.30	0.25	---	
1945-49	0.25	0.15	0.30	---	0.30	---	
1940-49	0.20	0.15	0.22	0.15	0.28	---	
1900-49	0.24	0.20	0.23	0.16	0.12	0.06	

TABLE V. **Fraction of Meteorite Falls and Finds for which Information was Published Within Certain Periods of Time.** The calculations were based upon the earliest reference in the Catalogue of Meteorites (Prior and Hey, 1953) for each meteorite.

	Period of Fall of Find	Number of Meteorites	Fraction "Reported" Within: 5 years	10 years	20 years	30 years	50 years
Falls:	1800 - 1850	115	0.67	0.73	0.77	0.82	0.92
	1850 - 1900	230	0.73	0.84	0.91	0.95	0.99
	1900 - 1950	291	0.71	0.86	0.95	0.98	1.00
	1800 - 1950	636	0.71	0.83	0.90	0.94	0.98
Finds:	1800 - 1850	20	0.50	0.70	0.95	1.00	1.00
	1850 - 1900	206	0.48	0.61	0.76	0.87	0.98
	1900 - 1950	362	0.62	0.79	0.92	0.98	1.00
	1800 - 1950	588	0.57	0.73	0.87	0.94	0.99
Falls + Finds:	1800 - 1850	135	0.64	0.73	0.79	0.84	0.93
	1850 - 1900	436	0.61	0.73	0.84	0.91	0.98
	1900 - 1950	653	0.66	0.82	0.93	0.98	1.00
	1800 - 1950	1224	0.64	0.78	0.88	0.94	0.99

TABLE VI. **Modification of the Number of Falls per Decade for the Twentieth Century Due to Major Conflicts and the Delay in Reporting Falls**

Decade	Present Number of Falls	Increase Due to Wars	Increase due to Delay in Reporting	Calculated Number of Falls
1900 - 09	54		1	55
1910 - 19	56	3	1	60
1920 - 29	64		3	67
1930 - 39	84		7	91
1940 - 49	40	4	6	50
1950 - 59	29		12	41

TABLE VII. **Meteorite Falls from 1860 to 1940 Contained in the Statistics of Two Authors**

Decade	Farrington (1915) 1910	Leonard (1941c) 1940	Present Total 1960
1860 - 69	51	53	55
70 - 79	46	49	49
80 - 89	37	40	41
90 - 99	39	46	47
1900 - 09	19	52	54
10 - 19		55	56
20 - 29		68	64
30 - 39		72	84

TABLE VIII. Fraction of Final Total of Falls Contained in Statistics After Certain Periods of Elapsed Time. These fractions were calculated from the data in Table VII assuming all falls for the period 1860-1900 have been reported by the present time and that the final total of falls for 1900-09, 1910-19, 1920-29, and 1930-39 will be respectively 55, 60, 68, and 91.

Elapsed Time (years)	Fraction in Statistics	
	Farrington	Leonard
5	0.35	0.79
15	0.83	1.00
25	0.90	0.90
35	0.94	0.95
45	0.93	0.98
55		0.98
65		1.00
75		0.96

TABLE IX. Summary of Results of the Chi-Squared Test for Randomness in the Synthetic Random Distributions

No. of Cases	Decade Distributions (deg. of freedom = 15) Chi-Squared	P	Ave. P	Monthly Distributions (deg. of freedom = 11) Chi-Squared	P	Ave. P
12				12.0	0.36	
12				4.0	0.97	
12				10.0	0.53	
12				4.0	0.97	0.71
20	13.6	0.56		8.8	0.64	
20	8.8	0.89		8.8	0.64	
20	23.2	0.08	0.51	8.8	0.64	0.64
24				4.0	0.97	
24				16.0	0.14	
24				9.0	0.62	
24				3.0	0.99	0.68
36				8.0	0.71	
36				11.0	0.44	
36				19.3	0.05	
36				8.0	0.71	0.48
40	20.0	0.17		10.4	0.49	
40	7.2	0.95		4.5	0.95	
40	13.6	0.56	0.56	9.8	0.55	0.66
48				4.0	0.97	
48				3.5	0.98	
48				5.0	0.93	
48				8.5	0.67	0.89
120	20.8	0.15		4.0	0.97	
120	16.5	0.35	0.25	13.8	0.24	0.61

TABLE X. Summary of Results of the Chi-Squared Test for Randomness in the Meteorite Distributions

	Decade Distributions			Monthly Distributions		
	No. of Meteorites	Chi-Squared	P	No. of Meteorites	Chi-Squared	P
Carbonaceous chondrites	10	12.0	0.68	17	13.5	0.26
Olivine-bronzite chondrites	50	11.2	0.74	53	13.4	0.27
Olivine-hypersthene chondrites	111	13.6	0.55	123	18.4	0.07
Veined-olivine-hypersthene chondrites	35	7.6	0.94	41	26.7	0.005
Low-iron chondrites	109	5.6	0.78	134	16.2	0.13
High-iron chondrites	65	13.5	0.14	77	13.3	0.28
Ca-rich achondrites	27	11.3	0.73	33	13.7	0.25
Irons	29	20.3	0.16	27	10.2	0.51

FIGURES

Fig. 1 Number of meteorite falls per decade.

Fig. 2 Meteorite falls per decade normalized to the world population.

Fig. 3 Synthetic random point distributions containing 20 points.

Fig. 4 Synthetic randon point distributions containing 40 points.

Fig. 5 Synthetic random point distributions containing 120 points.

Fig. 6 Month of fall vs. year of fall graphs for enstatite chondrites, olivine-pigeonite chondrites and carbonaceous chondrites.

Fig. 7 Month of fall vs. year of fall graphs for olivine-bronzite chondrites, olivene-hypersthene chondrites, and veined-olivine-hypersthene chondrites.

Fig. 8 Month of fall vs. year of fall graphs for low-iron chondrites and high-iron chondrites.

Fig. 9 Month of fall vs. year of fall graphs for calcium-poor achondrites, calcium-rich achondrites, and irons.

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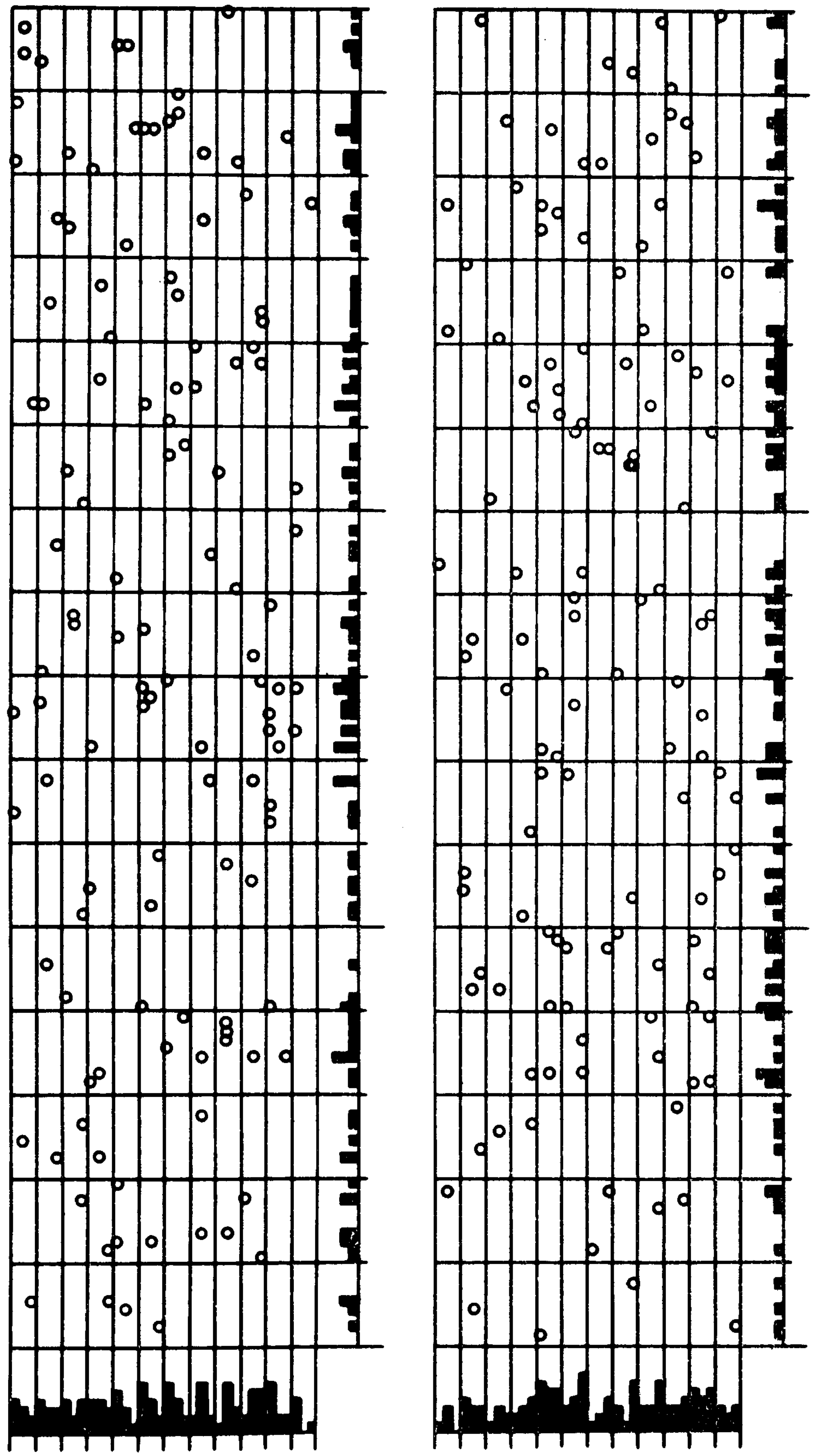
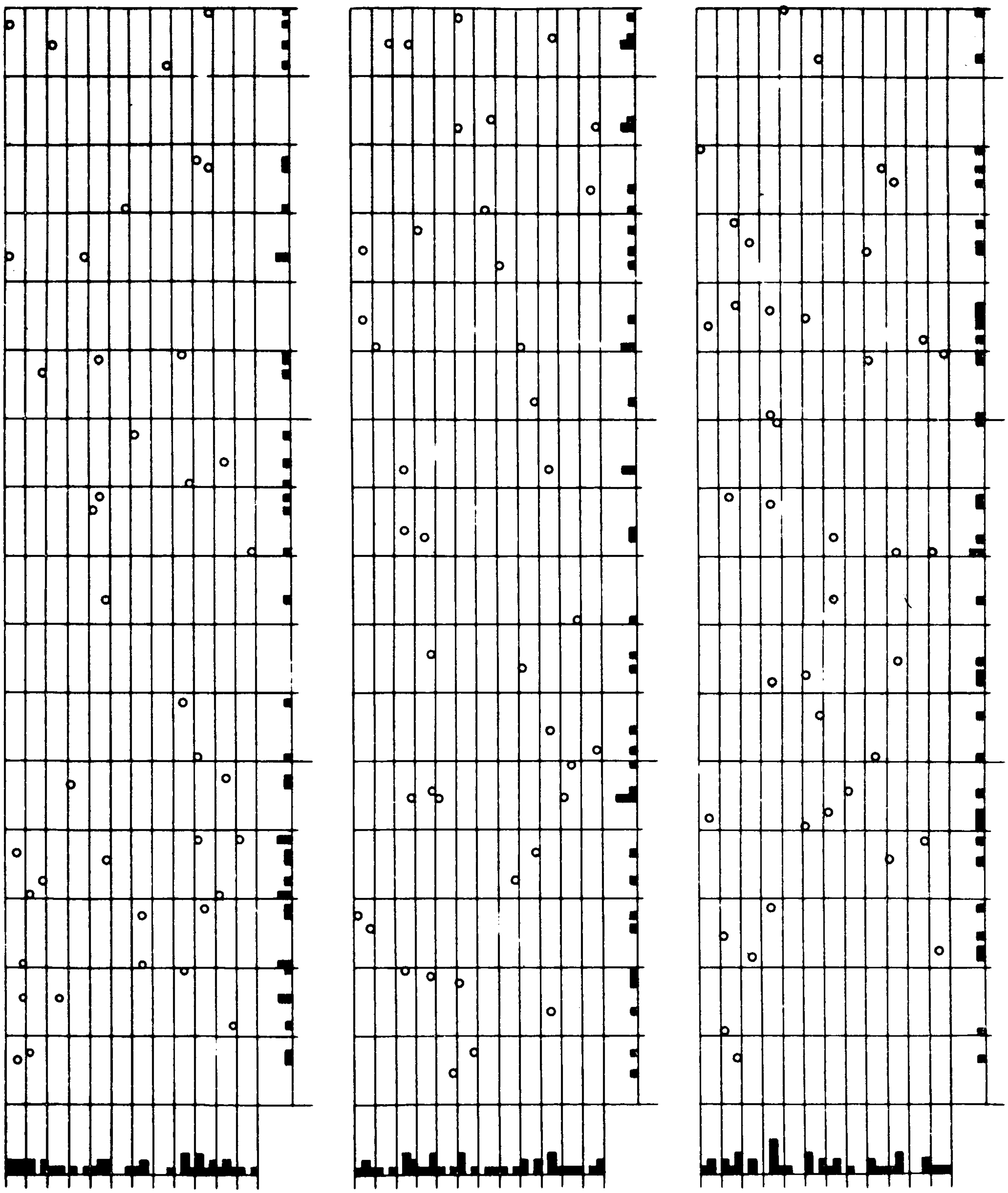
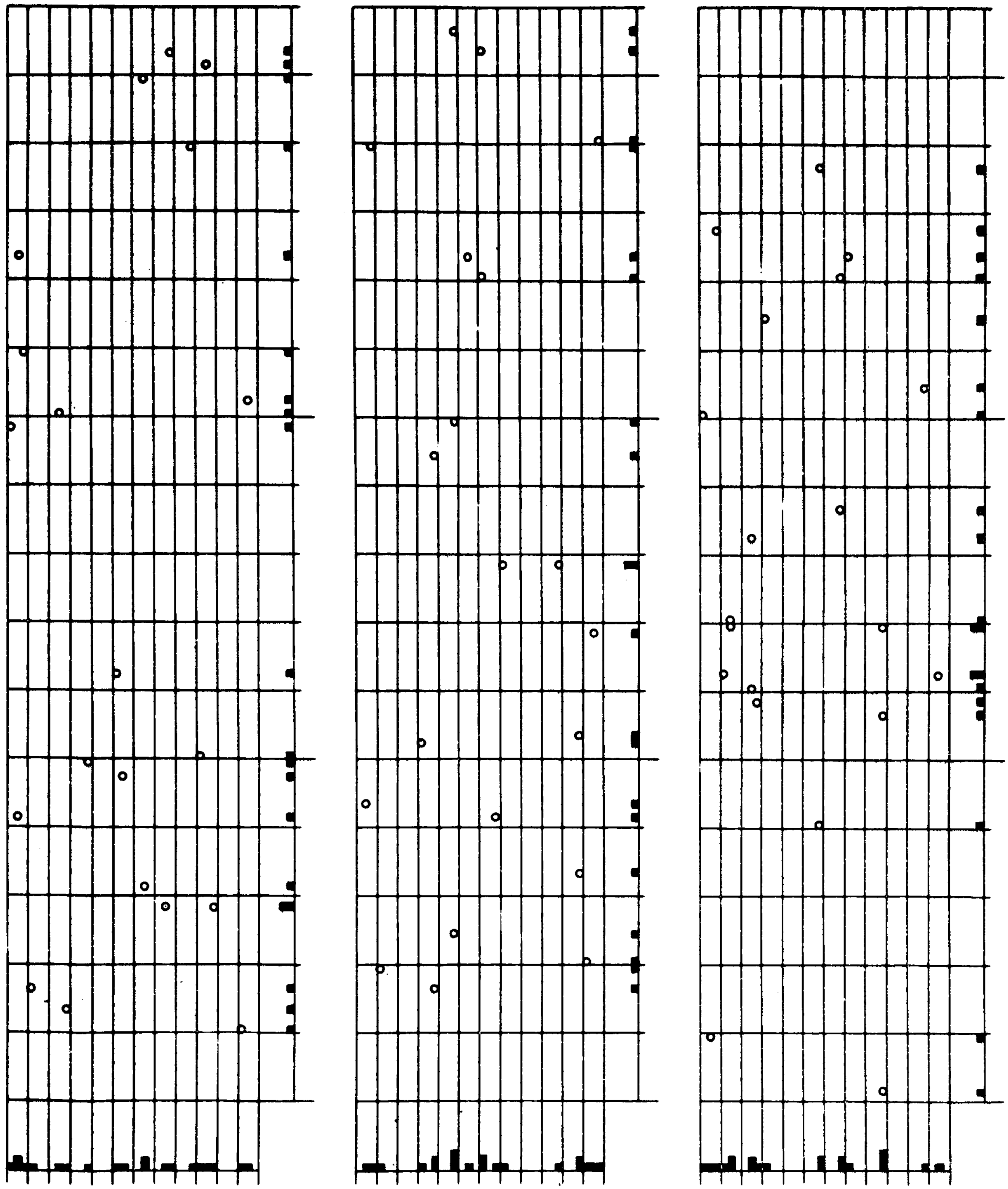
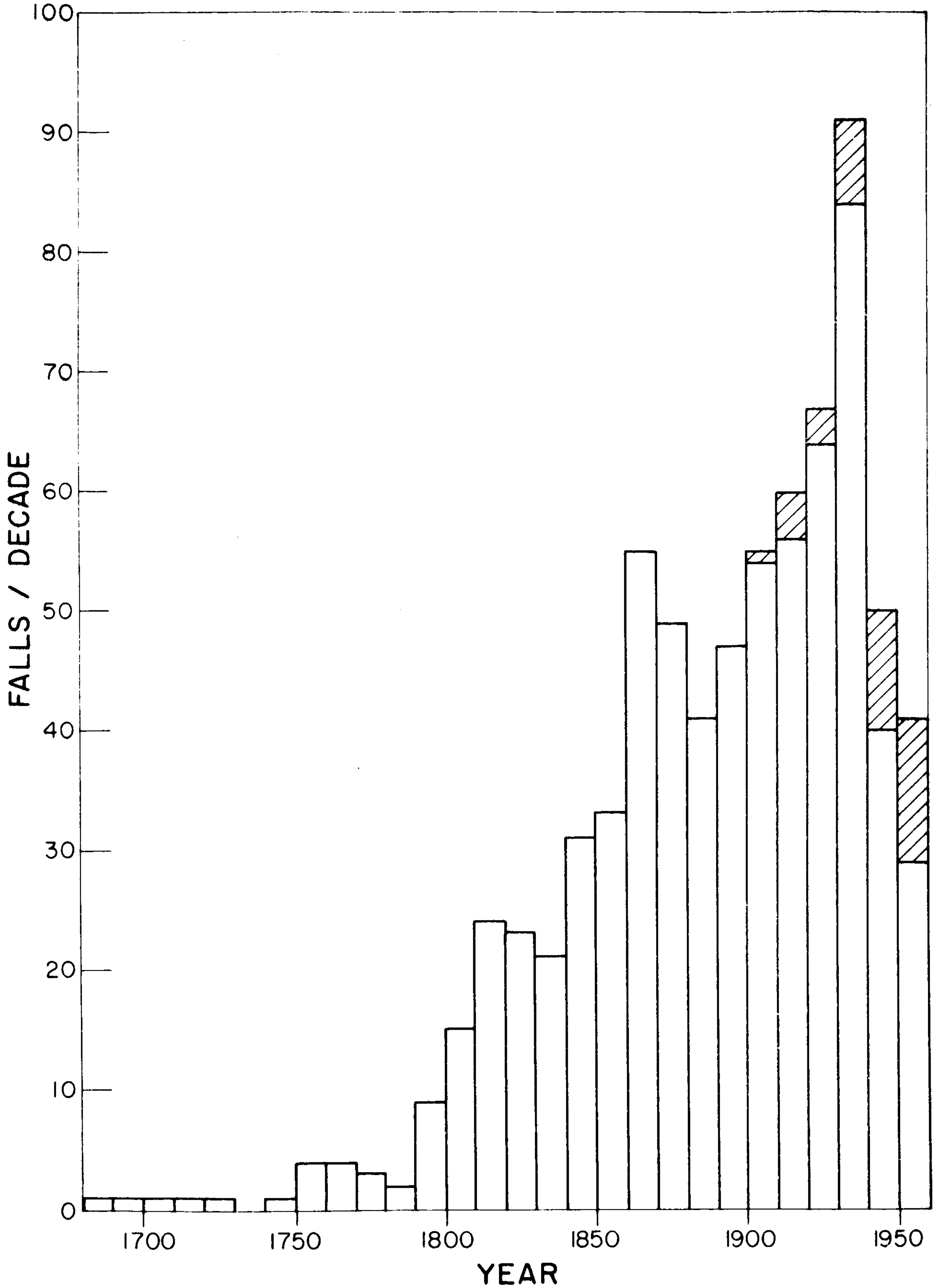
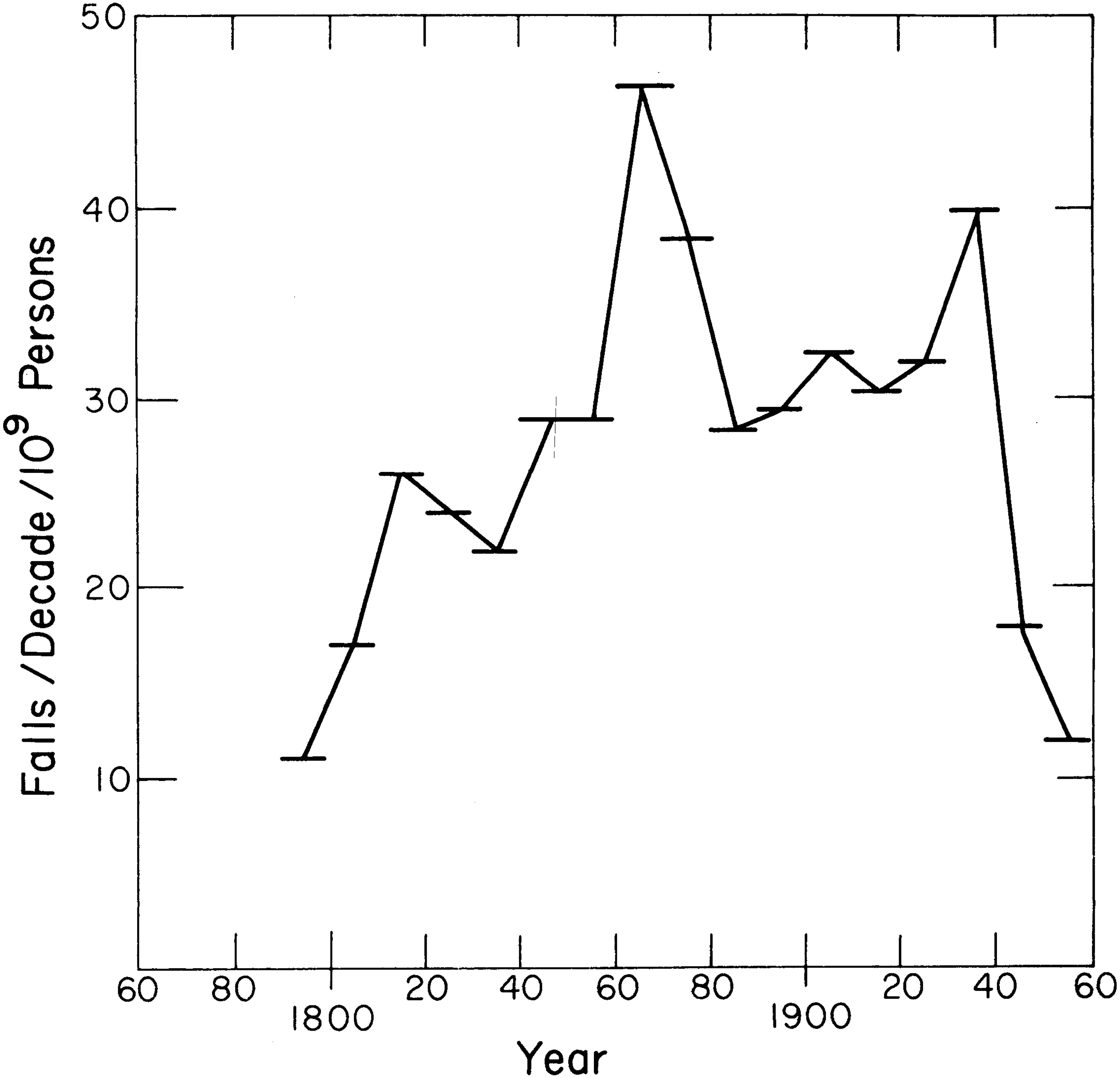


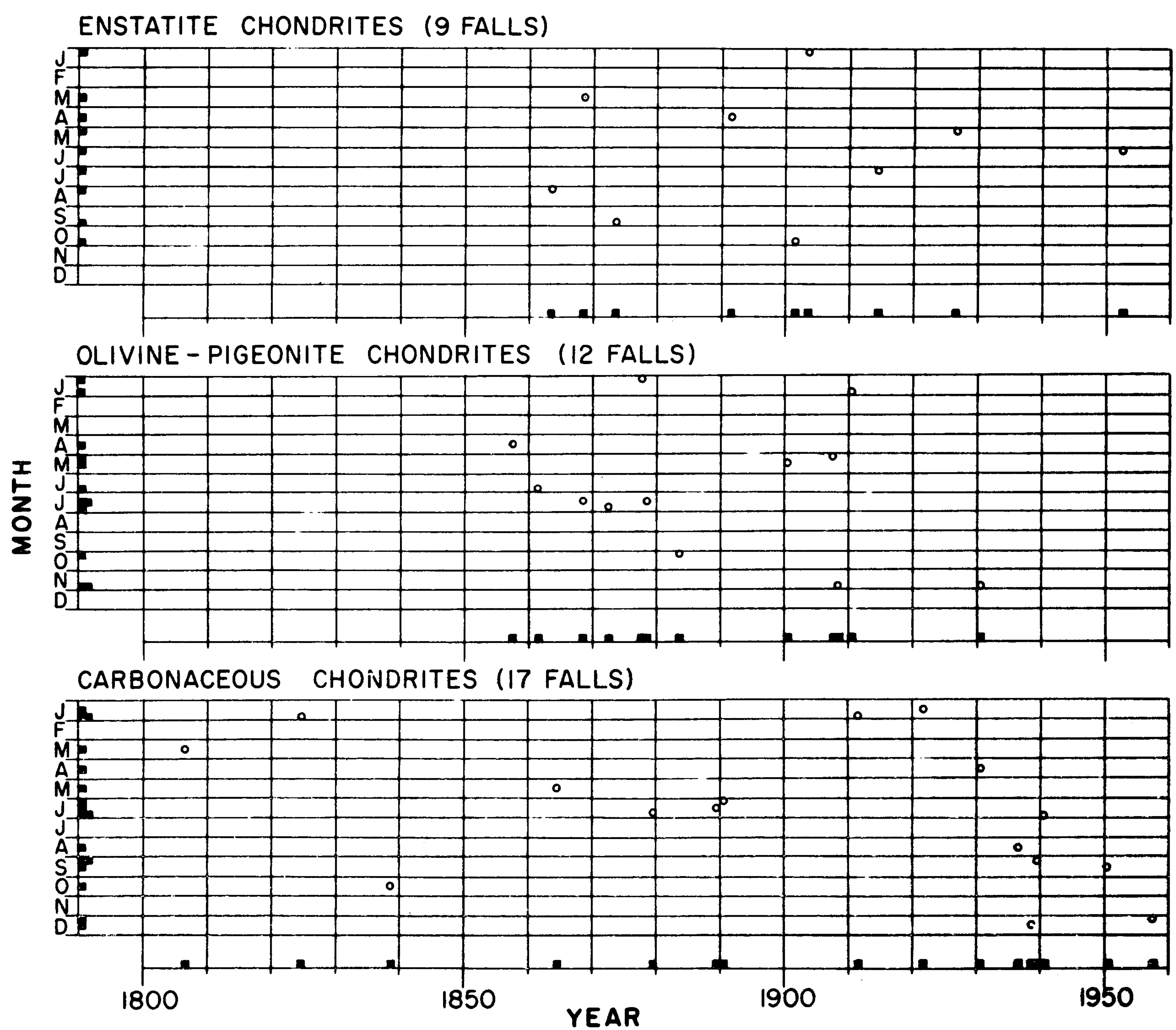




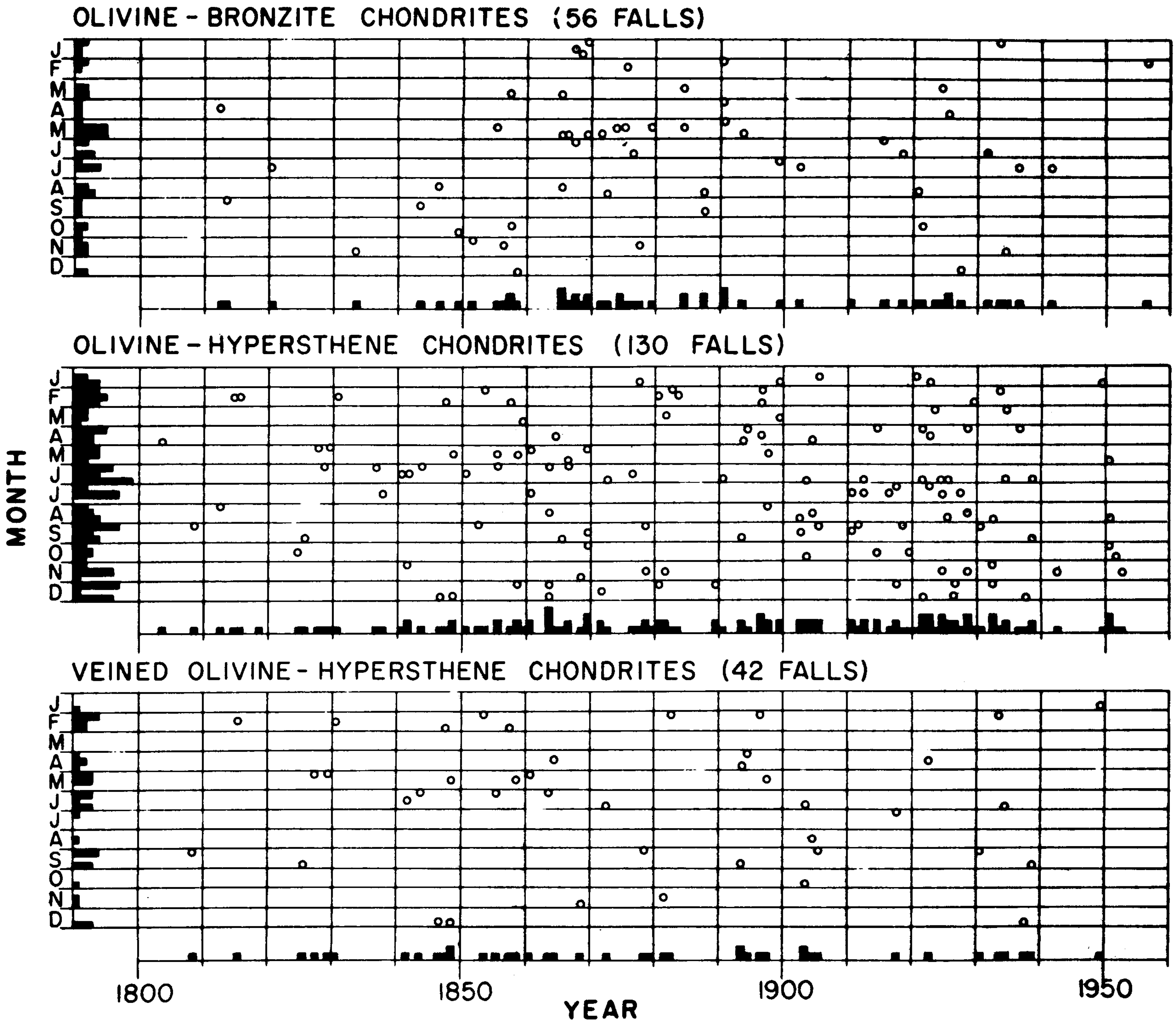

100
90
80
70
60
50
40
30
20
10
0
FALLS / DECADE
1700
1750
1800
1850
1900
1950
YEAR

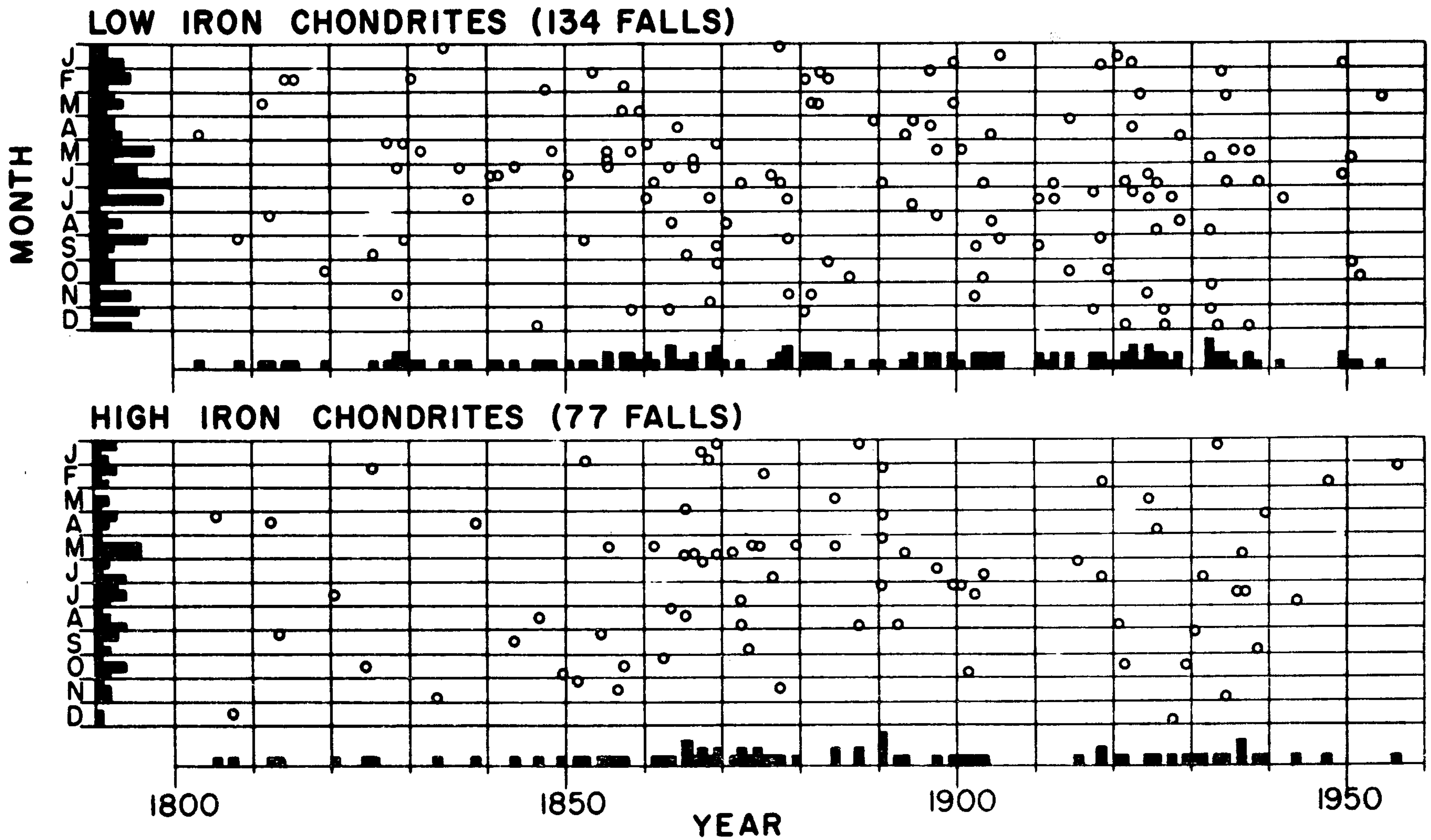


50
40
30
20
10
Falls / Decade / 10^9 Persons
60
80
1800
20
40
60
80
1900
20
40
60
Year

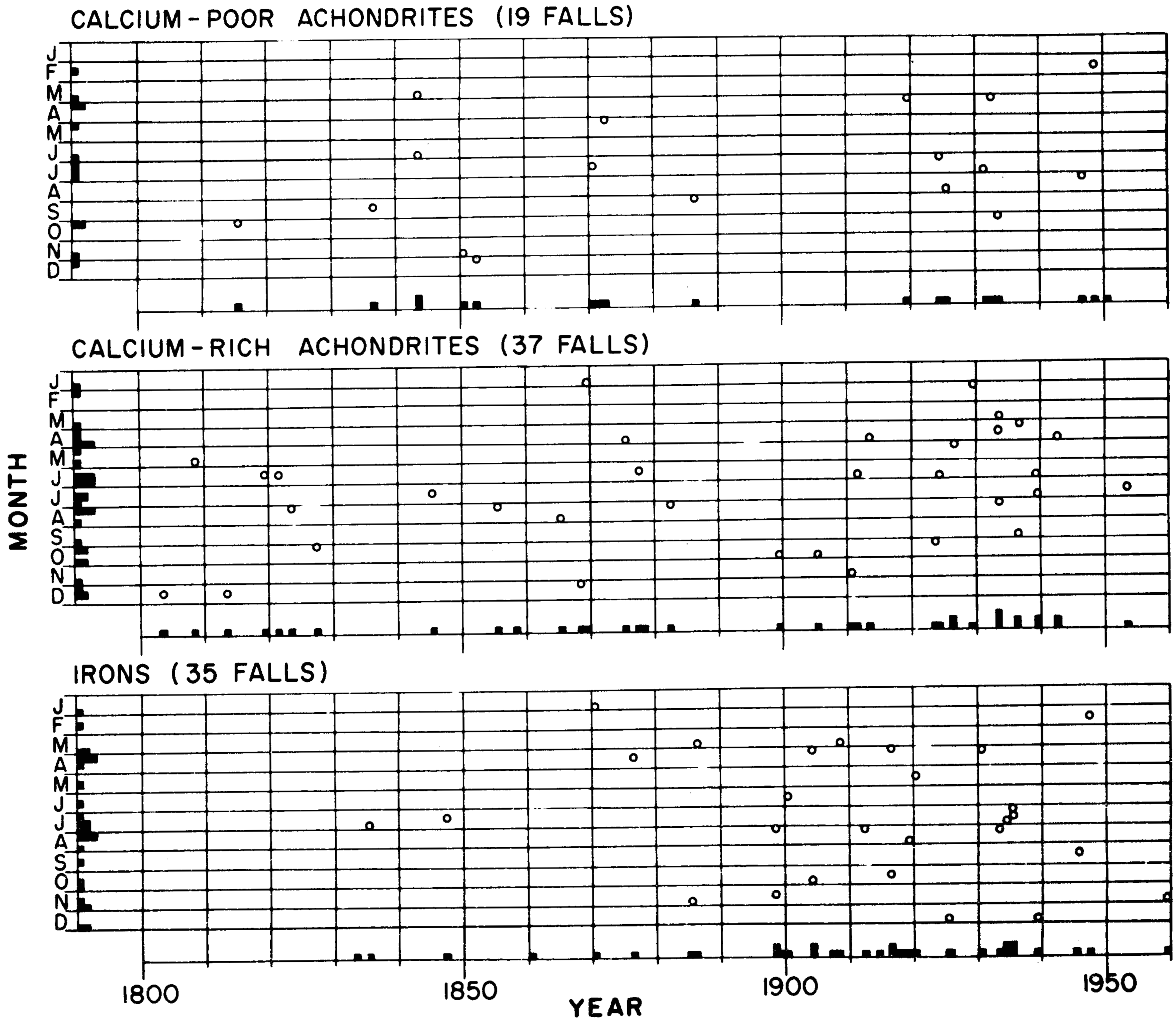


ENSTATITE CHONDRITES (9 FALLS)
OLIVINE - PIGEONITE CHONDRITES (12 FALLS)
CARBONACEOUS CHONDRITES (17 FALLS)
MONTH
J
F
M
A
M
J
J
A
S
O
N
D
YEAR
1800
1850
1900
1950


OLIVINE - BRONZITE CHONDRITES (56 FALLS)
OLIVINE - HYPERSTHENE CHONDRITES (130 FALLS)
VEINED OLIVINE - HYPERSTHENE CHONDRITES (42 FALLS)
MONTH
J F M A M J J A S O N D
YEAR
1800
1850
1900
1950



LOW IRON CHONDRITES (134 FALLS)
HIGH IRON CHONDRITES (77 FALLS)
MONTH
J
F
M
A
M
J
J
A
S
O
N
D
1800
1850
1900
1950
YEAR



CALCIUM - POOR ACHONDRITES (19 FALLS)
CALCIUM - RICH ACHONDRITES (37 FALLS)
IRONS (35 FALLS)
MONTH
J F M A M J J A S O N D
YEAR
1800
1850
1900
1950